RIPPLE-CURRENT REDUCTION SCHEMES FOR AC CONVERTERS

BACKGROUND OF THE INVENTION

[0001] The present disclosure is in the field of ripple-current reduction techniques and, more particularly, relates to the application of such techniques to power electronic circuits, particularly those of AC converters that include inductors.

[0002] Inductors are used in many ways in power electronic converters including operation as filters, energy storage and high frequency decoupling. In most cases a low frequency current and a high frequency ripple current will flow in the main inductor. This current is present due to the switching involved in the operation of power electronic circuits. An inductor may also be connected to a capacitor to create a low-pass filter to allow the flow of low frequency current and to reduce AC ripple of the desired voltage. A critical problem that arises in such circuitry is that ripple currents in a capacitor induce heating by reason of conductor losses and dielectric losses. The heating of the capacitor in turn reduces its life expectancy. Accordingly, any means that will reduce the ripple current into the capacitor has the potential to increase the life expectancy of a system that uses the capacitor. In addition, the reduction in the ripple current can reduce the required total capacitance which in turn can lead to a reduction in the size of the capacitor and, hence, of the system. This is conventionally achieved by the mechanism of defining a fixed allowable ripple voltage across the terminals of the main capacitor before and after the ripple current reduction. An alternative embodiment can be achieved by reducing the inductance value of the inductor and maintaining the capacitance as per the original design.

[0003] The existence of old techniques, or techniques that have become available recently, can reduce the ripple voltage on a capacitor and may include an increase in the frequency of the ripple current. Unfortunately, this can also increase the stress on the capacitor more than the benefits provided by a reduction in the ripple current amplitude. This consequence follows because the losses in the capacitor are frequency dependent. Also, the problem is exacerbated when the power level of the

converters is high. Another method has been used is to reduce the ripple voltage across the capacitor terminals by the addition of more filter components. However, since classic filter design requires that these filters carry the full power of the converter system, the cost of such additional filters outweighs the benefits. There is also difficulty in damping these complex filter arrangements. In addition, the total ripple can only be spread out between all the components.

SUMMARY OF THE INVENTION

[0004] The above noted problem in connection with AC converters has been overcome by the present disclosure wherein an AC ripple current reduction circuit is provided comprising an arrangement of a low frequency modulated high frequency AC voltage source at the input, and wherein a first capacitor is provided across which the circuit output voltage is obtained, a main inductor being connected in series with that first capacitor and the input and including an auxiliary circuit having a second capacitor whereby the flow of a time varying low frequency (AC) voltage across both of the capacitors is achieved, such voltage having a frequency much less than the ripple frequency of the current in the main inductor. There is a second inductor connected in series with the second capacitor and the transformer.

[0005] The benefits of the AC ripple reduction circuit of the present disclosure can be achieved by means of several embodiments. It can be realized in a single-phase form or expanded to include 3-phase AC circuits that can be configured to operate in Y or Δ-based configurations. Additionally, a zero sequence current version is provided for the AC ripple reduction circuit, wherein with this configuration the main inductor is placed between the neutral and the ground of a 3-phase Y-connected circuit. Accordingly, it will be appreciated that any current flowing in the ground path will also have its ripple component reduced in much the same manner as for a single-phase ripple current reduction circuit.

[0006] The foregoing and still further objects and advantages of the present disclosure will be more apparent from the following detailed explanation of the preferred embodiments of the disclosure in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Fig. 1 Depicts a first embodiment of the AC converter ripple reduction circuit;

[0008] Fig. 2 Depicts typical voltage and current waveforms for the circuit of Figure 1; the lower portion shows the "zoomed in" current waveforms;

[0009] Fig. 3 Shows an alternative embodiment for the single-phase AC ripple reduction circuit using polarized capacitors in the auxiliary circuit;

[0010] Fig. 4 Illustrates an implementation of AC ripple reduction circuit in a three-phase Y-connected system;

[0011] Fig. 5 Illustrates a three-phase delta connected circuit implementation of the ripple reduction circuit;

[0012] Fig. 6 Illustrates an implementation of AC ripple reduction circuit for zero sequence ripple current reduction; and

[0013] Fig. 7 Illustrates an alternative form of the zero sequence AC ripple current reduction circuit using inductors in the series path of the voltage nodes.

DETAILED DESCRIPTION

[0014] Referring now to Figure 1 of the drawings, the AC ripple current reduction circuit of one embodiment in accordance with the present disclosure is depicted. The AC ripple reduction circuit of Figure 1 includes an output capacitor designated C_{main}

and an auxiliary circuit capacitor designated C1, which have a time varying voltage across it with a frequency much less than the ripple frequency of the current in the inductor L_{main} seen in Figure 1.

[0015] It will be noted that in Figure 1 other elements are provided; that is, other than the main capacitor C_{main} and the auxiliary circuit capacitor C_1. The circuit also includes a low frequency modulated high frequency source of AC voltage V_{in} across the terminals 10 and 12; main inductor L_{main} is connected to the upper terminal 10, such that a series circuit is constituted by the connection of L_{main} to the output or main capacitor C_{main} across which an output voltage V_{Cmain} appears. An auxiliary circuit is connected from the output of L_{main} and includes, connected to terminal 12, the auxiliary capacitor C_1 which is connected in series with the secondary of transformer T_1 and an auxiliary inductor L_{aux}, as well as resistor R_{damp}, which is connected to the upper output terminal 14. The transformer T_1, whose secondary is connected as just noted, has its primary side connected across the main inducter L_{main}.

[0016] It will thus be understood from the description of Figure 1 that in the operation of the AC ripple current reduction circuit there is injected an opposing current I_{aux} of the ripple current into one end of the main inductor on the side connected to the main capacitor C_{main}. The return path of the injected current in the common of the main ripple voltage source and the main capacitor C_{main}. The main current is not present in the inverse ripple current and is derived from the main inductor current. As a result, the ripple current in the AC filter capacitor C_{main} is greatly reduced, thereby relieving the already noted stresses and losses in this capacitor, as well as increasing its filtering effectiveness.

[0017] It will now be apparent that there are several advantages provided by the present disclosure. The AC ripple current reduction circuit reduces the ripple current of the inductor in the attached capacitor. Hence, this circuit can be used to reduce the capacitance of the output and to reduce the stresses on the capacitor C_{main} connected to the inductor and carrying the ripple current. In addition, the auxiliary circuit already described of the AC ripple current reduction circuit carries only the main

ripple current amplitude; there is very little low frequency current component. This can be verified by reference to Figure 2 in which voltage and current waveforms on the circuit of the present disclosure have been depicted.

[0018] Figure 2 shows some typical voltage in current waveforms for the circuit of Figure 1. It can clearly be seen that the auxiliary current (I_{aux}) ripple is the inverse of the ripple current in the main inductor L_{main}. Also clearly shown is the low frequency AC voltages V_{C1} and V_{Cmain} across capacitors C_1 and C_{main}. The waveforms depicted in Figure 2 have been generated by means of a computer simulation.

[0019] The AC ripple current reduction circuit of the present disclosure has been shown in the one version or embodiment involving a single-phase circuit. However, the same circuit reduction principle is suitable for application to three phase circuits and can be used for either Y or Δ-base circuits, as well as zero sequence circuits, as will now be described.

[0020] Turning now to Figure 3, a slightly modified version of the ripple reduction circuit of Figure 1 is shown wherein polarized capacitors C_1 and C_2 are used in the auxiliary circuit. Hence, diodes D_1 and D_2 are shown in parallel, respectively, with C_1 and C_2. Polarized capacitors of this sort may be used for increased capacitance in the circuit. In some cases polarized capacitors exhibit higher losses, which translate to a higher equivalent series resistance (ESR) and can be used as all or part of the damping resistor (R_{damp}) of Figure 1. The diodes D_1 and D_2 can be rated with the low frequency of the system as they only conduct every half-cycle of the low frequency.

[0021] Referring now to Figure 4, this shows how the AC ripple reduction circuit can be implemented in a 3-phase Y-connected system. In this figure, three separate, slightly modified auxiliary circuits 100, 102, 104 are respectively connected to the respective inputs O1, O2, O3, at the U, V and W outputs of the respective portions of the Y connection and the other side of the auxiliary circuits are all connected to neutral end. Thus, the neutral conductor serves as the common return for the ripple

reduction circuits. Accordingly, it can clearly be understood that in this configuration the ripple reduction circuit is simply repeated for each phase.

[0022] Referring to Figure 5, depicted is a 3-phase Δ-connected implementation of the ripple reduction circuit. Unlike the 3-phase Y-connected circuit, no neutral is available for the return path of each of the ripple reduction circuits. In this case, the return path is provided by using the adjacent voltage node of another phase. This can be done as an effective high frequency return path has been created. There may be some phase shift in the voltage between the auxiliary circuit capacitor C_1 and the corresponding output voltage.

[0023] Figure 6 depicts the way the AC ripple reduction circuit for zero sequence operation is implemented. In this application the common return path is not available, and one has been created by splitting the auxiliary circuit capacitor into three capacitors C_1, C_2, and C_3, and connecting the capacitors to phase voltage nodes 150, 152, and 154, respectively, as seen.

[0024] Figure 7 shows an alternative form of the zero sequence AC ripple current reduction circuit that makes use of inductors in the series path of each of the voltage nodes. In this configuration the ripple current information of each phase is combined to derive the total ripple current that can be used for the reduction process. Once again, the common return path is not available and is artificially made in the same manner as described for the circuit of Figure 6.

[0025] In order to provide to the men skilled in the art information with respect to a source for the ripple circuit of Fig.1, an example for the source V_{in} is a well-known Pulse Width Modulated (PWM) inverter. The purpose of such an inverter is to convert a DC voltage to an AC voltage. Such an inverter would be made up of a DC-bus capacitor across which two switching devices are connected. The switching devices can be MOSFET (Metal Oxide Silicon Field Effect Transistor), IGBT (Insulated Gate Bi-polar Transistor) or other well known semi-conductor switches. The two switching devices are connected in series. The two switches can never be

turned on at the same time as this would constitute a short circuit across the capacitor. The switching devices are turned on and off in sequence such that the on-time of one will be the off time of the other and vice-versa. The switching devices are turned on and off at the rate of the switching frequency (or carrier) and is the high frequency component. The on-time (or off time for the other device) can then be modulated from a minimum to a maximum within the confines of the switching frequency time by a modulating frequency (low frequency). The center connection of the two switching devices form one connection of the source V_{in} and a common point to the capacitor, such as the positive, or negative terminal the other connection of the source v_{in}. This high frequency modulated with a low frequency voltage is then be filtered to extract the low frequency component for the output. A filter is used for this purpose and an example is one made up using L_{main} and C_{main}.

[0026] The inverter is similar to a DC to DC converter for example. The main difference between the DC ripple circuit and the AC ripple circuit of the present disclosure is the input voltage of the DC version only has one frequency (the carrier) and the AC version has two frequencies (the carrier and th4e modulator).

[0027] While the present disclosure has been described with reference to one or more exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the present disclosure. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the disclosure without departing from the scope thereof. Therefore, it is intended that the present disclosure not be limited to the particular embodiment(s) disclosed as the best mode contemplated for carrying out this disclosure, but that the disclosure will include all embodiments falling within the scope of the appended claims.